JOHN GLENN WORKING PAPER SERIES

Estimating the Restoration and Modernization Costs of Infrastructure and Facilities

Peter S. Lufkin

Anand Desai

Jay Janke

Working paper 2005-2
http:://kb.osu.edu

The John Glenn Institute for Public Service and Public Policy
And
The School of Public Policy and Management

Page Hall
1810 College Road
The Ohio State University
Columbus Ohio 43210-1336

Abstract

Under spending for the maintenance of public facilities and infrastructure is a well-known issue. At least part of the problem can be attributed to our poor understanding of precisely what funding is required. Methodological limitations diminish the credibility of budget estimates that, for many agencies, are based on ad hoc approximations or historical trends. Estimates based on physical inspections are more defensible, but are expensive and more useful for defining remedial projects than estimating future budget requirements.

Carefully defining facility restoration and modernization (R&M) requirements yields a collection of determinants—including obsolescence, changing uses, and extraordinary damage—closely related to the concept of economic depreciation. Once this link is made, the methods of economic capital theory are available for understanding R&M needs. More specifically, R&M costs can be estimated using depreciation rates, an approach useful for any large organization requiring credible R&M cost estimates, but unable to bear the costs of frequent physical inspections.

Peter Lufkin
Whitestone Research
509 East Montecito Street, Suite 201
Santa Barbara, CA 93103
plufkin@whitestoneresearch.com

Anand Desai
School of Public Policy and Management
The Ohio State University
Columbus, Ohio 43210
desai.1@osu.edu

Jay Janke
Deputy Director, Installations Requirements and Management,
Office of the Deputy Under Secretary of Defense
for Installations and Environment
U.S. Department of Defense
Jay.Janke@osd.mil

Estimating the Restoration and Modernization Costs of Infrastructure and Facilities

Maintaining and recapitalizing facilities require substantial expenditures by virtually all public and private organizations. In the U.S. these expenditures amounted to $192 billion in 1992, or roughly 40% of total construction-related activity. While considerable, these expenditures are widely regarded as insufficient to maintain the productive capacity of the nation's facilities and infrastructure.[1] Part of the problem is political: maintenance activities rarely have the same cachet as ribbon-cutting celebrations for new construction. But some part of underfunding must be attributed to the limited estimation tools available to facilities planners. Without credible empirical support it is difficult to make a case for the required funds.

Currently, there is no agreement even on defining maintenance and recapitalization activities, much less the appropriate tools for estimation. Planners are forced to rely on historical trends or ad hoc methods for approximating maintenance and repair requirements, especially for organizations with extensive facility holdings that preclude regular condition assessment inspections.

The Department of Defense (DoD), one of the world's largest property owners, provides a prominent example of the problem. Differences in methodologies, measures, and accounting procedures make comparison across military services difficult, and make Department-wide summations hard to calculate in a meaningful way. The result is uncertainty at the congressional level regarding actual facility funding requirements. As the General Accounting Office (1999) concluded:

> Given incomplete and inconsistent data, and different RPM [real property maintenance] rating systems among the services, the Congress cannot be

assured that it is funding maintenance and repairs that will provide the best return on its investment. (p. 2)

In response to this diminished credibility, DoD developed a two-part agenda to improve maintenance and recapitalization planning. The first part was defining a standardized classification of maintenance and recapitalization costs. According to this definition, facility requirements are classified as either sustainment costs—including maintenance and cyclical repair and replacement—or restoration and modernization (R&M) costs. This classification is now fully implemented in DoD planning and funding programming and is being adopted by a number of other federal departments.

The second part of the DoD agenda is to define methodologies for estimating sustainment and R&M funding requirements. A model for estimating sustainment funding based on scheduled maintenance tasks was developed in 2000 and is now routinely used by DoD and other agencies.[2] The requirement derived from this tool has become a commonly cited performance metric within DoD, and sustainment funding has risen from less than 80% to more than 95% of estimated costs since this approach was adopted.

The methodology used for estimating restoration and modernization is less resolved. Currently, R&M funding is based on a simple recapitalizaion rate calculated using assets' replacement cost and service life. For example, office buildings with a 50-year service life would have a recapitalization rate of 100/50 or 2% of replacement cost per year. Multiplying this rate by the replacement value of all office buildings, when repeated for all asset types, provides an overall DoD cost for recapitalization. Like the annual sustainment estimate, the recapitalization rate has also become a well-known metric that has focused attention on underfunding: recapitalization spending has risen from $2 to $4 billion since 2001.

But despite its acceptance, there is a concern that the recapitalization rate is an oversimplification and should be replaced or at least carefully validated. Its estimates are dependent on service life assumptions, for example, that are inconsistent with those used by other agencies and international organizations. Recalculating the example above assuming a more typical service life of 35 years would imply a recapitalization rate of 2.86% per year, and increase funding requirements by over 40%.

A more fundamental criticism is that there is no little or no data supporting the notion that facilities require recapitalization—due to obsolescence, for example—in the same fixed amount per year until the end of their service life. The recapitalization rate is the equivalent of straight-line asset depreciation for tax purposes, a practice that has little relationship to actual asset value. In fact, much of the facility management literature assumes that recapitalization requirements accelerate towards the end of service life.

These questions and the magnitude of the funding in question led DoD to consider alternative approaches for estimating the R&M requirement, an effort described in the remainder of this paper.

The Definition of Restoration and Modernization

For the purposes of this study, we define R&M as:

> Restoration includes repair and replacement work to restore facilities damaged or degraded by inadequate sustainment, excessive age, acts of war, natural disaster, fire, or accident. Modernization includes alteration of facilities solely to implement new or higher standards, to accommodate new functions, or to replace building components that typically last longer than the facility's expected service life. Together, restoration and modernization do not include sustainment, environmental compliance, or costs of historical preservation, which are funded

elsewhere. Other tasks associated with facility operations (such as custodial services, grass cutting, landscaping, waste disposal, and the provision of central utilities) are not included.[3]

Implicitly R&M includes no sustainment costs, although it does include penalty costs incurred from neglect. For example, a roof repair not done on schedule—a sustainment task—would not be included in R&M, but collateral damage—replacing joists due to roof leaks—would be considered R&M. Also not included in R&M are environmental compliance, specialized historical preservation, or facility operations costs.

According to this definition, there are six determinates of R&M requirements (the first three represent restoration the last three are related to modernization):

- **Acts of war and nature**. Unanticipated and often catastrophic damage requiring extensive capital expenditures. Grim examples include the damage to southern Florida from Hurricane Andrew in 1992 or destruction from recent terrorist attacks.
- **Neglect.** The requirements rising from "war and nature" repairs and sustainment tasks not done in a timely fashion. By definition this factor goes to zero if both sustainment and R&M have been accurately anticipated and fully funded.
- **Long-lived components**. Sustainment requirements are based on the repairs necessary over a normal facility service life. Facility components with service lives that exceed the "whole facility" service life—i.e. many exterior surface and closure elements, select electric and HVAC equipment—eventually will require repair or replacement.
- **Obsolescence**. Retrofitting or replacing facility components that are no longer the best technical or economic choice for their function.

- **Change in use**. Modifying facilities to suit a use other than that intended at design; i.e. adding force protection measures, increasing privacy in barracks, or adjusting older facilities to accommodate new weapon systems.
- **Change in legislation & codes**. Seismic retrofits and handicap accessibility improvements are examples of legislation-based R&M requirements.

A complete listing of the cost elements of both sustainment and restoration and modernization is provided in Table 1.

Alternative Approaches to Estimating R&M Requirements

In addition to the recapitalization rate currently used by DoD, there is a collection of approaches that could be used to estimate all or part of R&M costs. Ottoman, Nixon, and Lofgren (1999) identified 18 facility maintenance budgeting models.[4]

Many of these models do not address all of the elements of R&M: obsolescence, change in use, change in building codes, acts of war and nature, and neglect. In most cases, their focus is largely on sustainment costs (preventive maintenance and minor repair, unscheduled maintenance, major repair and replacement) rather than R&M.

A subset of models address facility "renewal" costs. Most of these are based on the assumption of fully replacing building subsystems at the end of the subsystem lifetime; knowing system costs and replacement schedules leads to calculating a crude profile of replacement or renewal costs over time. Philips (1989) describes such a schedule as the amount necessary "to offset aging" (p. 31); Hutson and Biedenweg (1989) use the same approach to estimate "future renewal and replacement costs" (p.15); Rush (1991) holds that such an estimate provides only for "component renewal" and does not address renovations, code changes, or damage from other than normal usage (p. 46); while Kaiser (1995) uses the same approach to budget for "deterioration, usage, and obsolescence" (p. 24). With the exception of Kaiser's broader interpretation, it seems that many renewal models apply to the major repair and replacement element of sustainment costs rather than restoration and modernization costs.

The only approach in the facility engineering literature consistent with the definition of R&M requirements is condition assessment, which involves actually inspecting facilities, identifying deficiencies, and estimating remediation costs. The U.S. Army ISR program is one of the most sophisticated of such systems (Uzarski and Burley, 1997), though there are many others, both among federal agencies and other organizations.

Unfortunately, the costs involved—often ranging from $0.10 to $0.15 per square foot for structures—make regular inspections prohibitively expensive, particularly for extensive facility inventories. Moreover, because of different inspection approaches and summary techniques, condition assessment results are difficult to compare across organizations. Finally, condition assessments provide point-in-time estimates that are valuable at the moment, but lose relevancy with the passage of time. Assessments have limited value for the facility planner responsible for long-run funding projections, and offer no utility in anticipating new facilities' costs.

The Link Between R&M and the Economic Depreciation of Structures

Our definition of restoration and modernization includes a collection of apparently unrelated costs documented only in the facility management literature. Considered individually, these costs—natural disasters and wars, neglect, long-lived component replacement, obsolescence, change in use, and building code revisions—are difficult to measure, much less forecast. However, from the perspectives of tax policy and economic capital theory, these costs are collectively captured in the concept of depreciation.

Federal Taxation

In their history of federal tax policies, Barzell, Dworin and Walsh (1989) note that the Bureau of Internal Revenue originally defined depreciation in 1914 as:

> the estimated amount of the loss accrued during the year…in the value of the property…that arises from exhaustion, wear and tear, or obsolescence out of the uses to which the property is put, and which loss has not been made good by payments for ordinary maintenance and repair. (p. 4)

According to this early view, depreciation could be expensed only to the extent that it reflected actual loss of value. But a short time later (1918) new rules were enacted that made depreciation simply an allocated amount calculated to recover capital costs over service life. Since then, the schedule of depreciation for fixed assets has had no necessary relationship to the loss of value. Granville (1999) describes the recent history of depreciation deductions for structures and notes eight times since 1953 that the depreciation approach—straight-line, declining balance, sum-of-year digits—and depreciation lives have been changed.

Public Utilities

Much of the theory of depreciation has evolved from the case history regarding regulated industries and allowable depreciation expenses. According to the U.S. Supreme Court:

> Depreciation is the loss, not restored by current maintenance, which is due to all the factors causing the ultimate retirement of the property. These factors embrace wear and tear, decay, inadequacy and obsolescence. Annual depreciation is the loss that takes place in a year. (*Lindheimer v. Illinois Bell Telephone Company*, 1934)

As with federal tax policy, quantifying depreciation by public utilities is based on recovering investment in an asset over its prescribed service life, rather than the actual change in asset value over time. There is no necessary correspondence between actual depreciation and allocated depreciation expense over the asset life.

According to the National Association of Regulatory Utility Commissioners (1996) depreciation expense is most often determined on the basis of straight-line depreciation from an estimated service life, though alternative patterns of depreciation are also used.

National Accounting

The Bureau of Economic Analysis (BEA) provides estimates of net capital stocks that require estimates of asset depreciation. According to Katz and Herman (1997) the BEA definition of depreciation is:

> the decline in value due to wear and tear, obsolescence, accidental damage, and aging.

The history of BEA depreciation estimates takes a course opposite that of public utilities and the Treasury, a methodological shift away from depreciation as an allocated cost and towards a view of depreciation as measurable loss of value. In 1976, the BEA stopped using tax-based depreciation methods and adopted an approach (straight-line depreciation by age cohort, retirements based on Winfrey curves, *Bulletin F* service lives) thought to reflect assets' actual economic depreciation. In 1997, BEA switched from straight-line depreciation to a geometric pattern for most assets, again intending to better measure actual economic depreciation.

In summary, our review of selected depreciation practices found common elements in what we term restoration and modernization, and what other organizations term depreciation. We also found that, despite a common definition, methods for estimating depreciation differ; for tax purposes and utility rate determination, depreciation is calculated at a prescribed rate over a specified period, and may only coincidently have any relationship with loss of value.

Economists, on the other hand, estimate depreciation as the actual loss of asset value. We suggest that the actual loss of asset value is equivalent to required R&M funding, and the economic models developed to estimate depreciation could also be used to estimate R&M (see Appendix).

Estimating Economic Depreciation

The key assumption in studies of economic depreciation is that changes in value (used-asset sale price, rental rate) fully capture the effects of physical deterioration and obsolescence as an asset ages.

Economic depreciation is often represented as an age–price profile. While there are a large number of possible depreciation profiles or patterns, three are often cited with respect to structures; each represents a different view of the decay of productive capacity over time (see Figure 1). A straight-line pattern assumes the depreciation occurs in equal increments over time, with the entire asset's value exhausted at the end of service life. A geometric pattern assumes that depreciation occurs at a constant rate in a shape concave to the origin, while a one hoss shay or "light bulb" pattern assumes that most depreciation occurs towards the end of service life.[5] Hulten writes:

> Of these patterns, the one hoss shay pattern commands the most intuitive appeal. Casual experience with commonly used assets suggests that most assets have pretty much the same level of efficiency regardless of their age—a one-year-old chair does the same job as a 20-year-old chair, and so on. (1990, p. 124)

Though not the most intuitive model, an extensive review of depreciation patterns concluded that the geometric pattern best represents structures' depreciation (Fraumeni, 1997). It was argued that the geometric pattern was found to fit empirical data at least as well as other distributions, and estimates of geometric rates of depreciation are readily available. This review describes revising the U.S BEA methodology to use geometric depreciation rates rather than the straight-line approach used prior to 1997.[6] Also included in this review is a list of depreciation rates, service lives, and estimated declining balance rates for individual asset classes.

The geometric rates of depreciation adopted by BEA were taken largely from estimates derived by Hulten and Wykoff (1980). In the case of structures, these estimates were based on a 1972 Treasury Department survey of building owners. Respondents were asked their building's acquisition price, acquisition year, and construction year—the data necessary to construct age–price profiles for 16 classes of structures. The authors concluded that a geometric function provided an adequate representation of a more complex statistical model, and reported the estimated rates of depreciation shown in Table 2.[7]

How accurate are the Hulten and Wykoff (H&W) estimates? In the case of office buildings, the estimated geometric rate was 1.05%, or 2.47% after adjusting for retirements.[8] A 1998 study of office buildings by Colwell, Munneke, and Trefzger estimated depreciation to be roughly 2%, unadjusted for building retirements. Adding the 1.4 point increase Hulton and Wykoff saw after adding retirements to their sample would increase this estimate to 3.4%. A 2002 Deloitte and Touche study estimated a rate of 3.46 from a sample of buildings aged 20 years or less. Here it was argued that by failing to account for capital improvements, earlier studies underestimated depreciation. These comparisons suggest that even with retirement adjustments the H&W results are probably conservative.

As an example, when the age–price profile for office buildings is calculated for both the geometric and straight-line patterns, comparison reveals the different outcomes with alternative depreciation practices (see Figure 2). For instance, a straight-line pattern has been used historically for tax depreciation schedules and public utility rate studies, and the approach's inconsistency with actual observed depreciation has long been an issue.

Decreasing values for the geometric profile were calculated as $1-(1-\delta)^t$, where t is building age and δ is the geometric rate (2.47) estimated by H&W. Decreasing values for the straight-line profile were calculated as 1-(t/T), where T is the service life (36 years) specified by BEA.

The profiles' relative shape clearly indicates that geometric depreciation is less than the straight-line function. This is true for all structures—but not necessarily for other types of fixed assets. For example, for industrial machinery the arc of the geometric pattern is closer to the origin than the straight-line pattern, indicating that in the earlier years geometric depreciation is accelerated.[9]

Do the two distributions lead to meaningful differences in estimated depreciation? For the geometric pattern accumulated depreciation is obviously less—roughly 60% or an average 1.6% per year over service life—when compared with 100% depreciation at an average of 2.7% for the straight-line distribution.

Figure 2 also demonstrates a very meaningful difference from a widely held assumption in the facility management literature. In this literature, the capital assets require recapitalization according to a one-hoss shay type of distribution shown in Figure 1.[10]

Issues in Measuring Economic Depreciation

Gravelle (1999) and others have identified a number of potential problems with price-based depreciation measurements.[11] The basic issue is isolating the effect of depreciation—the loss of value related to physical depreciation and obsolescence over service life—from other effects.

Censored sample bias. A sample of aged structures is likely to provide understated depreciation estimates unless the sample is adjusted to account for structures already retired.

The "lemons" problem. Goods sold as used have a larger percentage of "lemons" than the overall population of goods of the same vintage.[12] As Gravelle puts it for cars, "owners tend to keep their cream puffs and trade in their lemons" (p. 4). Thus using sales data for structures has a potential to overstate depreciation.

Vintage effects. Particular vintages of structures may last longer than others. There is a general assumption—though little empirical proof—that older structures are built with better materials and superior workmanship, and thus have longer service lives. Other vintages may have a specific appeal that lead to an unusual increase in value—one example is Victorian homes in U.S. markets in the 1970s and 1980s. Underestimating service life will lead to overestimating depreciation, while a fashion-driven price increase would lead to underestimating depreciation (once tastes change).

Effects of reinvestment. Substantially renovating structures enhances their value and, if unrecognized, leads to underestimating depreciation that would exist in the absence of reinvestment.

Effects of unforeseen obsolescence. For some assets an unforeseen technical advance or sudden change in relative price of inputs (e.g. the 1974 oil shock) lead to an asset retirement before the end of the service life considered in the purchase decision.[13]

This is different from the foreseen obsolescence reflected in long-term sales data. Unforeseen obsolescence is probably less frequent for structures than for assets such as electronic equipment or heavy equipment. However, changes in building codes (earthquake, fire protection, handicap access, asbestos abatement, etc.), changes in technology (raised flooring, LAN wiring, open office cubicles) or changes in use (DoD shift from dormitory to apartment-style barracks) could lead to premature structure retirement. In this case depreciation would be underestimated.

Effects of catastrophe. An unusual event such as natural disaster or act of war leads to an asset's sudden destruction. Including data from such damaged or retired structures would overestimate depreciation.

Each of these concerns has implications for adopting the geometric approach (or other value-based models) to estimate R&M requirements. The first four issues were addressed in either the original H&W work or in subsequent discussions: the censored sample bias was explicitly accounted for in their original model; the lemons problem was determined to be unimportant by finding that the geometric pattern fit both types of assets—those likely to have a lemons bias and those that did not; and observed stability in geometric rates over time argued against tax effects or the ability of other economic factors to influence depreciation.

On the other hand, the effects of reinvestment have received little attention in the many discussions of the H&W results. The H&W study was based on a sample of thousands of buildings of various ages, and it is almost a certainty that some had been "recapitalized."

As noted above, this would lead to higher resale values and biased (lower) depreciation estimates. Conversely, buildings not properly maintained would have the opposite effect. The actual balance in the two types of buildings—recapitalized versus neglected—is unknown.

The effects of unforeseen obsolescence would be reflected in depreciation estimates only: as with reinvestment, such obsolescence occurred in the underlying sample. We assume this is unknown, though it might be determined from re-examining the H&W sample. For the purposes of R&M estimates, it seems reasonable to assume that these costs are not included in the estimates, and—together with the effects of catastrophe—should be removed from our definition of R&M.

Using Economic Depreciation Rates to Estimate R&M Funding Requirements

Estimating R&M requirements for an extensive facility or portfolio of facilities using economic depreciation rates is relatively straightforward:

- Categorize the inventory value by asset type and age.
- Assign an age–price distribution (calculated from the appropriate depreciation rate) to each asset type.
- Multiply the facility replacement value by the respective depreciation rate for each asset type and age cohort.

An example of R&M estimates using depreciation rates is shown in Table 3. For each of four asset types a geometric rate calculated by BEA was used to estimate the average annual R&M cost over a given service life. The last column is a judgment as to how well the original Hulten and Wykoff rates relate to the BEA classification.

Note that annual R&M estimates can be estimated two ways, depending on the facility data available. If only the facility replacement value is known, then annual R&M costs can be estimated using the Mean Annual R&M, expressed as a percentage of plant replacement value (PRV). If facility ages are also known, than age-specific R&M costs can be estimated using the Rate of Depreciation. For example, annual R&M costs for hospitals age 20 years would be calculated as the difference in the facility's value facility at year 19 $(1-.0188)^{19}$, and year 20 $(1-.0188)^{20}$, or 1.32% (.6973 minus .6841) of PRV.

Interpreting the Estimates

It is important to understand the depreciation-based estimates in the context of the earlier definition of R&M. These estimates approximate the facility value lost—or inversely the amount necessary to restore original productive value—due to natural disasters and wars, long-lived component replacement, obsolescence, change in use, and building code revisions. This *depreciation occurs even when facilities are fully sustained*, that is, all preventive maintenance, minor repairs and major repairs and replacement tasks are done. In the event that facilities are not fully sustained, the R&M estimates are understated to the extent that depreciation is accelerated by a "neglect" factor.[14]

R&M estimates can be reported as an annual requirement or a cumulative measure of depreciation over facility lifetime. For example, in the absence of any R&M funding (or recapitalization) over a 20-year period we can approximate a "backlog" of R&M for a 20-year-old hospital of $1-(1-.0188)^{20}$, or roughly 32% of PRV. Note this is not a substitute for actual inspections of developing specific recapitalization projects and their costs, but does provide an order of magnitude estimate and also can help prioritize inspections: Which assets have the highest likely projected backlog?

Sources of Economic Depreciation Rates

Using the depreciation approach for a large and heterogeneous inventory of capital assets requires specific depreciation rates for each type of asset. These rates are potentially available from three sources.

First, economic depreciation can be directly observed from actual transaction data. Facility sales or rental agreements can provide direct evidence of particular assets' age–price profiles. Insurance settlements are another source of age–price data.

Second, the age–price distribution can be statistically derived from survey data, as with the Hulten and Wyckoff studies. We noted earlier that these rates have also been used by analogy, e.g., adjusting for service life, for assets for which no price data is available.

And third, the age–price distribution can be imputed from knowing the asset's age–efficiency profile. Here efficiency means the value (price times quantity) of service provided by the asset, which in market terms can be expressed as the rental rate. The asset's price in a competitive market at each age is the cumulative discounted value of the rental revenue over the asset's service life.[15]

Summary

At least part of problem of underfunding for facilities and infrastructure is due to the lack of credible and practical estimation tools. R&M funding requirements often rely on ad hoc rules of thumb or on historical funding trends that only perpetuate underfunding. Regular physical inspections are costly, quickly outdated, and more useful for project development than long-range budgeting.

In our search for a more useful methodology, we first defined the sources of R&M costs, and recognized that there is a close correspondence with the concept of depreciation from (economic) capital theory. Economic depreciation has been a subject of study since the early 1800s, and as such offers a vocabulary, body of theory, and set of empirical models that can be applied to R&M issues.

More specifically, we argue that seminal studies by Hulten and Wykoff (1980) and Fraumeni (1997) provide estimates of economic depreciation that can also be used to estimate R&M costs. Based on minimal data requirements—asset description, age, and service life—this method can be used for estimating annual R&M funding requirements, and also to approximate the cumulative "backlog" of R&M requirements. This approach would be useful for any large organization requiring a credible estimate of current and future R&M costs, while avoiding the costs of frequent physical inspections.

Tables

Table 1

Sources of Sustainment and Restoration & Modernization Costs

Sustainment	Preventive Maintenance and Minor Repair Unscheduled Maintenance Major Repair & Replacement
Restoration & Modernization	Replacement due to Obsolescence Change-in-use Modifications Policy-mandated Retrofits Acts of War and Nature Repairs from Neglect Long-lived Components

Table 2

Deprecation Rates

Structure Class	Annual Depreciation[a] %
Apartment	3.36
Bank	5.07
Factory	3.61
Medical Building	8.48
Motel	4.92
Office	2.47
Recreational	4.87
Repair Garage	4.00
Restaurant/Bar	4.34
Retail Trade	2.20
Service Station	10.80
Shopping Center	3.36
Terminal	5.63
Warehouse	2.73

[a] Geometric approximations based on Box-Cox estimates, with the respective samples adjusted for retirements. Source: Hulten and Wykoff, 1980.

Table 3

Average R&M Costs for Selected Asset Types

BEA Asset Type	Rate of Depreciation	Service Life	Mean Annual R&M (% PRV)	Hulten-Wykoff category
Hospital and Institutional Buildings	.0188	48	1.25	B
Office Facilities	.0247	36	1.65	A
Commercial Warehouses	.0222	40	1.48	A
Industrial Buildings	.0314	31	2.03	A
Electrical Transmission, Distribution and Industrial Apparatus	.0500	33	2.47	C

Note. Geometric depreciation rates are taken from Fraumeni (1997). Hulten and Wykoff estimates are not all derived from primary data. The authors categorized their estimates as A, estimated from age-price data; B, estimates from secondary sources and informed judgment; and C, estimates imputed from average declining balance rates for all category A and B type assets. See Hulten and Wykoff (1980).

Figures

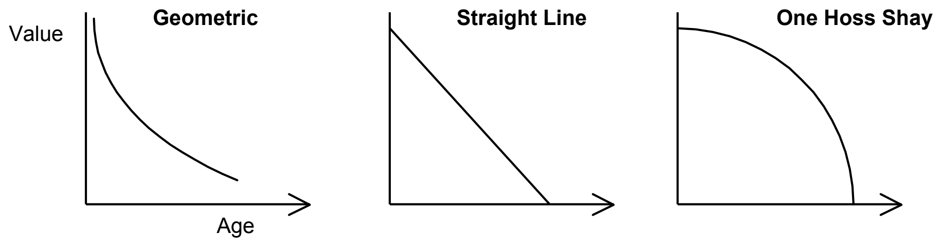

Figure 1. Alternative Age–Price Profiles

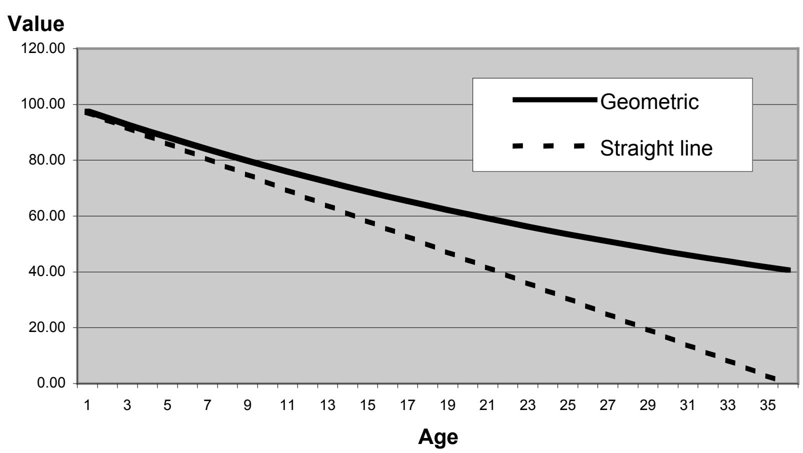

Figure 2. Straight-Line and Geometric Depreciation for Office Buildings

References

Ackerlof, G. (1970). The market for lemons: Quality uncertainty and the market mechanism. *Quarterly Journal of Economics, 83*, 3.

Atwell, R. (1989). Foreword. In S. Glasner (Ed.), *Critical Issues in Facility Management: Vol.4. Capital Renewal and Deferred Maintenance* (pp. xi). Alexandria, VA: Association of Physical Plant Administrators.

Barzell, D., Dworin, L., & Walsh, M. (1989). *A history of federal tax depreciation policy*. OTA Paper 64. Washington, DC: Office of Tax Analysis, U.S. Treasury Department.

Building Management Information. (2002). *Review of maintenance costs 2002*. London: RICS Building Cost Information Services Ltd.

Colwell, P., Munneke, H., & Trefzger, J. (1998). Chicago's office market: Price indices, location and time. *Real Estate Economics, 26*, 1.

Deloitte and Touche LLP. (2000, June). *Analysis of the economic and tax depreciation of structures*. Washington, DC: Author.

Federal Facility Council. (2001). *Deferred maintenance reporting for federal facilities*. Federal Facilities Council Technical Report #141. Washington, DC: National Academy Press.

Federal Facility Council. (1998). *Stewardship of federal facilities: A proactive strategy for managing the nation's public assets*. Washington, DC: National Academy Press.

Fraumeni, B. (1997, July). The measurement of depreciation in the U.S. national income and product accounts. *Survey of Current Business*, pp. 7-23.

Gravelle, J. (1999). *Depreciation and the taxation of real estate*. Washington, DC: Congressional Research Service, Library of Congress.

Hotelling, H. (1925). A general mathematical theory of depreciation. *Journal of the American Statistical Association, 20*, 340-353.

Hulten, C. R. (1990). The measurement of capital. In E. R. Berndt & J. E. Triplett (Eds.), *Fifty years of economic measurement: Vol. 54. Studies in income and wealth* (pp. 119-152). Chicago: The National Bureau of Economic Research, University of Chicago Press.

Hulten, C. R., & Wykoff, F.C. (1980). Economic depreciation and the taxation of structures. In D. Usher (Ed.), *The measurement of capital: Vol. 45. Studies in income and wealth* (pp. 83-109). Chicago: The National Bureau of Economic Research, University of Chicago Press.

Hutson, R., & Biedenweg, F. (1989). Before the roof caves in: A predictive model for physical plant renewal. In S. Glasner (Ed.), *Critical Issues in Facility*

Management: Vol.4. Capital Renewal and Deferred Maintenance (pp. 13-29). Alexandria, VA: Association of Physical Plant Administrators.

International Facility Management Association. (1997). *Benchmarks III*. Houston: Author.

Jacobs Facilities and Whitestone Research. (2002, May). *Support and extension of the Department of Defense sustainment model*. Santa Barbara, CA: Author.

Jacobs Facilities and Whitestone Research. (2001, January). *Implementation of the Department of Defense sustainment model*. Santa Barbara, CA: Author.

Kaiser, H. (1995). Preventing deferred maintenance. *AIPE Facilities, 22*(5), 24-31.

Katz, A., & Herman, S. (1997, May). Improved estimates of fixed reproducible tangible1 wealth, 1929-25. *Survey of Current Business*, 69-92.

Lindheimer v. Illinois Bell Telephone Company, 292 U.S. 151, 167 (1934).

McGrattan, E., & Schmitz, J. (1999). Maintenance and repair: Too big to ignore. *Federal Reserve Bank of Minneapolis Quarterly Review*, *2*, 13.

National Association of Regulatory Utility Commissioners. (1996). *Public utility depreciation practices*. Washington, DC: Author.

Organization for Economic Co-operation and Development, Economic Statistics and National Accounts Division, Statistics Directorate. (2001, January). *Measuring capital*. Paris: Author.

Ottoman,G., Nixon, W., & Lofgren, S. (1999, July/August). Budgeting for facility maintenance and repair, I: Methods and models. *Journal of Management in Engineering*, American Society of Civil Engineers (ASCE), 15(4), 71-83.

Parke, C., & Sharpe-Bette, G. (1990). *Advanced engineering economics*. New York: Wiley.

Philips, C., Jr. (1989). Facilities renewal: The formula approach. In S. Glasner (Ed.), *Critical Issues in Facility Management: Vol.4. Capital Renewal and Deferred Maintenance* (pp. 30-46). Alexandria, VA: Association of Physical Plant Administrators.

Plexus Scientific Corporation and Whitestone Research. (2003, January). *Backlog of Maintenance and Repair (BMAR) Limits Study: An Alternative Approach*. Santa Barbara, CA: Author.

Rush, S. (1991). *Managing the facility portfolio*. Washington, DC: National Association of College and University Business Officers.

Statistics Canada. (Annual). *Survey on Capital and Repair Expenditures*. Ottawa: Author.

U.S. Government Accounting Office. (2003). *Defense infrastructure: Changes in funding priorities and strategic planning needed to improve the conditions of military facilities*. GAO-03-274. Washington, DC: Author.

U.S. Government Accounting Office. (2003). *High risk series: Federal real property*. GAO-03-122. Washington, DC: Author.

U.S. Government Accounting Office. (1999). *Military infrastructure: Real property management needs improvement*. NSIAD-99-100. Washington, DC: Author.

U.S. Treasury Department, Internal Revenue Service. (1942). *Bulletin F: Depreciation rate tables*. Washington DC: Government Printing Office.

Uzarski, D., & Burley, L. (1997). Assessing building condition by the use of condition indexes. In M. Saito) (Ed.), *Infrastructure condition assessment: Art*, *science, and practice* (pp. 365-374). New York: American Society of Civil Engineers.

Appendix: Calculating Geometric Depreciation

With geometric depreciation, the market value in constant prices is assumed to decline at a constant rate in each period. The depreciation factor can be written as *R/T* where *T* is the service life and *R* is known as the "declining balance rate." Depreciation for period t is obtained by multiplying the asset's written down value in the period *t-1* by the depreciation factor, *R/T*. There are several ways of calculating the declining balance rate (*R*).

One method commonly used by commercial accountants is known as the "double declining balance" method. With this method, *R* is set at 2. The effect of this is that, in the first period, depreciation will be twice as large as depreciation calculated by the straight-line method. (It is for this reason that the method is referred to as "double-declining.")

Another approach is to set *R* at a value that ensures that the asset's initial value will have been reduced to a predetermined percentage (*g*) of that value by the time it reaches the end of its expected service life. In other words, a value of *R* is required such that:

$$V\,(1 - R/T)^{T} = gV$$

Dividing by *V* and solving for *R* gives:

$$R = T(\,1 - g^{1/T}\,)$$

With *g* set at 0.1 (i.e. 10% of the initial value remains at time *T*) a service life of 15 years gives *R* = 2.135, which implies slightly more rapid depreciation than the double-declining method; *R* increases as service lives get longer, and for a 50-year service life, *R* rises to 2.250.

A third approach is to use evidence drawn from empirical studies of secondhand asset prices to determine the declining balance rate appropriate to each asset. This has been done in the United States where the Bureau of Economic Analysis (BEA) uses *R* values that range from 0.8892 for most office and commercial buildings to 2.2664 for federal government vehicles. These R values are then divided by specific asset service lives to define the depreciation factor. In this way the R value of a similar asset can be used to approximate the depreciation factor for another asset, when the service life is known.

Note: Much of this section is taken from OECD (2001), Chapter 7. For a more applied discussion of depreciation methods, see Park & Sharp-Bette (1990), Chapter 4.

[1] The Federal Facilities Council (1998, "Stewardship") estimated that actual maintenance funding for federal real property was less than 2% of replacement costs, while the appropriate amount should be 2 to 4%. GAO (2003, "High Risk") estimated backlog restoration and modernization tasks to total "tens of billions of dollars." The problem of underfunding facilities is not unique to federal agencies. A survey of industry facilities (International Facility Management Association (IFMA), 1997) found that 75% of respondents were spending less than 2% of replacement value on maintenance; an earlier survey of American universities (Atwell, 1989) found that a backlog of 20% of replacement value was average for its respondents. Nor is the problem unique to the U.S; a survey of local governments in England and Wales (Building Management Information (BMI), 2002) found less than 50% of estimated M&R needs were being funded.

[2] The sustainment model is used to generate annual cost factors for over 400 facility types. These factors are updated annually and posted at whitestoneresearch.com/fsm/. Various implementation issues regarding the sustainment model are discussed in Jacobs Facilities and Whitestone Research (2001).

[3] This definition was originally proposed in an earlier study, "Support and Extension of the Department of Defense Sustainment Model" (Jacobs Facilities and Whitestone Research, 2002), Section 4.

[4] Also see Federal Facilities Council (2001) for a review of methods for reporting deferred maintenance costs.

[5] The term "one hoss shay" is taken from Oliver Wendell Holmes' poem "The Deacon's Masterpiece or the Wonderful One Hoss Shay," in which a horsedrawn coach is so well constructed that it shows no wear for 100 years—at which point it suddenly falls apart.

[6] BEA now uses geometric rates to depreciate most fixed assets in the National Income and Products Accounts (NIPA).

[7] Not all estimates by Hulten and Wykoff were derived directly from age–price profiles. The authors categorized their estimates as A, estimated from age–price data; B, estimates from secondary sources and informed judgment; and C, estimates imputed from average declining balance rates for all category A and B type assets.

[8] Winfrey curves and average service lives were used to calculate the likely number of retired assets by age, and this number of records was added to the respective samples for each structure type. Asset value for the added records was set to zero.

[9] Paul Lalley (BEA) suggested this example (personal communication, October 4, 2003).

[10] See for example, Federal Facilities Council (1998, pp. 13).

[11] This discussion focuses on depreciation as measured in asset sale value. Other approaches impute depreciation from rental data, estimate depreciation from capital values at two points of time, or make estimates on the basis of straight-line depreciation and service lives. Each approach has advantages and shortcomings but, as noted in a previous section, recent reviews have favored the H&W approach.

[12] See Ackerlof (1970) for the classic discussion of this problem.

[13] The System of National Accounts adopted by the Organization for Economic Co-operation and Development (OECD) distinguishes between foreseen and unforeseen obsolescence in its definition of the consumption of fixed capital. Foreseen obsolescence is the decline in value "as a result of physical deterioration (or wear and tear), normal obsolescence or normal accidental damage. It excludes the value of fixed assets destroyed by acts of war or exceptional events such as major natural disasters…" (2001, pp. 29-32).

[14] In a recent study for NASA we proposed that depreciation-based estimates of R&M represented a "floor" or minimum requirement (Plexus Scientific Corporation and Whitestone Research, 2003). Thus when inspection indicated a requirement above these amounts it was an indicator that past sustainment and recapitalization efforts were insufficient.

[15] See OECD (2001, ch. 7) for a thorough discussion of the relationship of age–efficiency to age–price profiles.